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EVOLUTION OF METHANE DETECTING DEVICES FOR COAL MINES

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L. C. ILSLEY AND A. B. HOOKER

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EVOLUTION OF METHANE DETECTING DEVICES FOR COAL MINES[1]

By L. C. Ilsley[2] and A. B. Hooker[3]

INTRODUCTION

The greatest hazard of early mining was from explosions of methane ignited by open lights. With the advent of safety lamps and forced ventilation this hazard was greatly reduced until the application of electricity to modern mining not only multiplied the sources of gas ignition but the accompanying machines and haulage systems increased the amount of explosive dust, through which a methane explosion is more liable to become a major mine disaster, and thus greatly furthered the need of adequate ventilation to keep down the concentrations of methane.

Adequate ventilation is still the best preventive of such explosions. However, even with a well laid out and controlled ventilating system the amount of air passing through entries and rooms is liable to vary within wide limits because of open doors, falls of rock, or other accidental causes. The percentages of methane under normal conditions should therefore be kept so small that they will not be increased to explosive proportions by short interruptions in ventilation.

Mine ventilation and methane detection are inseparable safety precautions. The increasing importance of ventilation necessitates more accurate determinations of the methane concentrations throughout the mines.

This paper discusses in detail some of the steps in the development of methane detection and specially notes the more accurate detectors now available.

One of the earliest means of detecting methane was by a candle. About 1835, John Buddle, Sr., a noted mining man of his period, when questioned by a Parliamentary Committee as to the safety of using candles, replied:

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Yes, I consider it a very great protection, the using of candles. It keeps every man upon the alert; we never can by the use of the Davy lamp judge the quantity of air passing so well as we can do with the candle.

Twenty years earlier, in 1813, Buddle, in a communication by letter, gave the following details as to testing for methane with a candle:

The common pit candles vary in size, but those generally used are forty-five to the pound; the wick is of cotton, and the candle made of ox or sheep tallow; but clean ox tallow is the best.

The mode of trying the candle, as it is called, to ascertain the mixture of inflammable gas, is as follows:

In the first place, the candle, called by the colliers the "low", is trimmed, that is, the liquid fat is wiped off, the wick snuffed short, and carefully cleaned of red embers, so that the flame may burn as purely as possible.

The candle being thus prepared, is holden between the fingers and thumb of the one hand, and the palm of the other hand is placed between the eye of the observer and the flame, so that nothing but the spire of the flame can be seen, as it gradually towers above the upper margin of the hand. The observation is generally commenced near the floor of the mine, and the light and hand are gently raised upwards, till the true state of the circulating current be ascertained.

The first indication of the presence of inflammable air is a slight tinge of blue, or bluish grey colour, shooting up from the top of the spire of the candle, and terminating in a fine extended point. This spire increases in size, and receives a deeper tinge of blue as it rises through an increased proportion of inflammable gas, till it reaches the firing point; but the experienced collier knows accurately enough all the gradations of "shew" (as it is called) upon the candle, and is very rarely fired upon, excepting in cases of sudden discharges of inflammable gas.

This shew upon the top of the candle varies very much according to the length of run, or distance, which the current of air has passed through, before it is mixed with the inflammable gas. The shorter the run of the current of air, before it is mixed with the inflammable gas, the less will be the shew upon the candle when at the firing point, and vice versa.

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William Clifford, an American mining engineer, left the following record as to the foregoing practice:

> In early days there were employed in mines a class of persons called "Candle Watchers"; and men became very expert in detecting firedamp with an open light, and in judging generally of its constituent character in this rude way -- the writer well remembers his first lesson in this practice from an old miner.

With such crude ideas as to what constituted safety, it was but natural that one disaster followed another with startling losses of human life.

There is no record as to who first discovered that a flame becomes elongated in the presence of methane, nor is there any record as to when this discovery was made; however, it can be safely stated that the candle flame was undoubtedly the earliest of the many schemes that have been devised for methane detecting. About 1816 the Davy flame safety lamp was introduced into coal mines. Although this lamp afforded a very poor means of illumination, its flame could be used in much the same manner as the candle to indicate the amount of methane present in the mine atmosphere and it was safer. Hence this device can well be regarded as the first safety methane detector.

Since the introduction of Davy lamps, there have been a great many attempts to develop detectors that are more satisfactory than flame safety lamps. This has been especially true during the latter half of the period. These efforts, good, bad, and indifferent, are matters of record in the patent files of the various coal-producing countries. The task has proved difficult, so much so that none of the numerous inventions has completely solved the problem of providing a cheap, reliable methane detector suitable for general use; this is attested by the fact that flame safety lamps are still generally used in American mines for detecting methane.

Flame-Type Detectors

Many of the early inventors continued to make use of the principle of the elongation of a flame in the presence of methane in their search for a better methane detector. Some of the more noteworthy designs will be briefly described.

(a) The Gray oil-burning lamp, designed by T. Gray, H. M. assistant inspector of mines for Great Britain in 1868, was a departure from previous types. It had four tubes with openings near the top of the lamp which brought the air to an annular space below the wick. A sample of the air close to the roof could be collected by this arrangement. The ventilation, however, was poor, and the lamp was later modified to what is known as the Ashworth-Hepplewhite-Gray (A-H-G) lamp, which was similar to the Gray lamp, except that it had three inlet tubes instead of four, and two of the inlet tubes had openings near their base which permitted air to enter the lamp and improved the ventilation. While samples of mine air were being taken, these

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openings could be closed by sliding shutters attached to the tubes. A later model of the A-H-G lamp had four tubes instead of three.

(b) The Clowes lamp, designed by Prof. Frank Clowes, University College, Nottingham, England, was an A-H-G lamp with an attachment for producing a hydrogen flame. The oil flame was used except when tests for gas were made; then it was extinguished and the hydrogen flame used. The hydrogen flame burned at the top of a copper tube, and its height was regulated by a valve. The hydrogen flame lengthened in the presence of methane, and by means of a scale for reading the elongation it was claimed that amounts of methane as low as one fourth of 1 percent could be detected.

(c) The Stokes lamp, designed by A. H. Stokes, H. M. inspector of mines, Great Britain, also made use of the A-H-G oil-burning lamp, to which was attached an alcohol vessel. The oil flame was used for general illumination and the alcohol flame for detecting gas. The tube-like metal alcohol container could be screwed into a small opening through the oil vessel. When the lamp was not in use for gas detection this opening could be closed with a plug which was fastened to the lamp with a chain. The alcohol flame was said to indicate as low as one half of 1 percent of methane.

(d) The Pieler, an alcohol-burning lamp designed about 1884 by Pieler, an Austrian engineer, was essentially a bonneted Davy with a very long conical gauze. Surrounding the flame was a short cone-shaped metal chimney. In the bonnet was a glass- or mica-covered slit, through which the height of flame could be seen. A graduated scale helped to determine the amount of methane present. It was claimed that as little as one fourth of 1 percent of methane could be detected with this lamp.

(e) The Chesneau lamp, designed by G. Chesneau, a French engineer, used methyl alcohol fuel to which was added some copper nitrate and ethylene chloride. This lamp was reported to be more satisfactory in operation than the Pieler, not only reaching normal condition in a given atmosphere much more rapidly, but withstanding higher air velocities with safety. It was claimed that the Chesneau lamp would indicate as low as one fourth of 1 percent of methane.

(f) The Fleissner singing flame lamp is representative of alarm types of flame-lamp detector. This detector depends for its action upon certain relations between the burner, sound tube, and flame size that produce a warning note or sound. The burner and sound tube are fixed, and the flame size depends upon the amount of methane or other combustible gas present and the adjustment of the wick height.

To obtain even approximate determinations or warnings it is necessary to adjust the flame in air to the prescribed height. If higher initial wick flame is used the detector will operate at lower percentages; it may even operate with no gas present.

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American Practice: Flame safety lamps are in general use in American mines for detecting methane in coal-mine atmospheres. Most of the coal-mining States have regulations in their safety codes requiring the use of methane-detecting equipment. The following excerpt is quoted from the Bituminous Mining Laws of Pennsylvania:

> Detection of Gas: In working places where gas is likely to be encountered, a safety lamp, or other suitable apparatus for the detection of fire damp, shall be provided for use with each machine when working, and should any indication of fire damp appear on the flame of the safety lamp, or other apparatus used for the detection of fire damp, the person in charge shall immediately stop the machine, cut off the current at the nearest switch, and report the matter to the mine foreman.

In general, American lamps are naphtha burning and of standard size; they are equipped with magnetic locks, double gauzes, and a bonnet. Steel and brass frame lamps are mostly used because of their inherent strength, but aluminum-frame lamps are much used by mine officials for testing because of their lighter weight. The lamps are furnished either in the flat- or round-wick models and with either steel or brass gauzes.

A small lamp (Baby Wolf) has been redesigned for distinctly gas-detecting service. It is lightweight, but because it gives very little illumination it is used only with other sources of light such as an electric cap lamp.

Nonflame-Type Detectors

With the introduction of portable electric safety lamps in mines there have been developed various kinds of nonflame-type detectors most of which depend upon electric current from small storage batteries for their operation. The successful makes of these detectors may be placed in three groups: namely, (1) the combustion type; (2) the diffusion type; and (3) the catalytic type. The following are representative detectors of these groups:

Group 1 (Combustion Type).- The Burrell detector developed by G. A. Burrell of the Bureau of Mines, is essentially a U-tube, one end of which terminates in a gas reservoir or combustion chamber and the other end in a gage glass having a calibrated scale. To make a test, water is forced into the gas reservoir by blowing into a rubber tube at the upper end of the gage glass. When the water is allowed to return to its original level it draws a measured sample of the atmosphere to be tested into the combustion chamber. The level of water returning to the 0 percent mark on the gage glass indicates that the full volume of the sample has been taken. The methane is burned from the sample by means of an electrically heated filament. The contraction in volume due to the burning is shown by a new position of the water level in the gage glass which indicates the percentage of methane in the original sample.

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The Burrell detector gives relatively accurate determinations of methane percentage when used according to the manufacturer's instructions. About 5 minutes are required for each determination; therefore, it is not adaptable to regular fire-boss service, its chief use being by mine officials in checking fire-boss reports or making mine-ventilation studies.

Group 2 (Diffusion Type).- The N and K (Neufeldt and Kuhnke, German) methane detector depends for its action upon the difference in speeds of diffusion of gases through a porous material.

The essential parts of this detector are an earthenware porous cup, an aspirator bulb for getting the test sample into a chamber around the cup, a manometer to show changes of pressure in the cup, and a source of compressed air for flushing the cup and its surrounding chamber after each determination.

The Ringrose (English) detector embodies the same principle as that of the N and K detector, but the application is quite different. The Ringrose detector has an electrically heated filament in the porous cup which burns the methane as it enters, so that instead of an increase there is a decrease in pressure proportional to the percentage of methane present. Burning the methane in the cup eliminates the necessity of flushing between determinations; that is, the detector is continuous in operation.

As approved by the British Mines Department, this detector is combined with an electric hand lamp; the change of pressure in the porous cup operates a diaphragm contactor which lights a red signal bulb. The contactor is set to operate at a definite percentage of methane. The device is therefore primarily an alarm. Its use as a methane detector is very limited.

Group 3 (Catalytic Types).- The fundamental principle involved is the same for all detectors of catalytic group - namely, that metals of the platinum group under certain conditions act catalytically with methane and produce sufficient heating of the metal to change its color or electrical resistance, or both.

If the metal is in a finely divided state, such as spongy platinum, the action is much more pronounced. Platinum wire is active in high percentages of methane when moderately preheated, about 250° C.; it is active in low percentages only at higher temperatures.

Many catalytic-type detectors have been developed, most of which have proved impractical for mine use; however, a few of these detectors will be mentioned to show some of the applications of the catalytic principle, and three detectors of more successful design will be described in greater detail.

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The Aitkin detector had two thermometers. The bulb of one of these was enclosed by a mass of spongy platinum and was thus heated above the other in proportion to the percentage of methane present. This detector did not indicate low percentages of methane and was subject to error in any percentage because of changes in the condition of the sponge platinum.

The Liveing detector had two coils or filaments of platinum wire of equal resistance. One of these coils was mounted in a gauze-protected cylinder with a glass end. The other was mounted in an air-tight cylinder with a glass end which faced that of the first cylinder. In pure air both coils glowed with equal brightness when an electric current was passed through them, but when the gauze-protected coil was in an atmosphere containing methane it glowed with increased brightness according to the proportion of methane present. A photometric screen moving over a suitably calibrated scale was used to obtain light balance between the two coils, and the methane content of the atmosphere could then be read directly from the scale. The device was said to be sensitive to methane, but was unsatisfactory as a detector because of the delicate adjustments required. Repeated heating of the exposed coil caused its electrical resistance to change; therefore, periodic zero setting of the scale in fresh air was required.

The Martienssen detector is a visual type in which the percentage of methane is estimated by the color of a heated platinum filament. The filament is a No. 40 gage platinum wire mounted as an inverted U. The top or middle portion has a partial coating of porous metallic palladium, making a roughened coating of 2 to 5 times the diameter of the wire.

When connected to its 2-volt battery and surrounded by air, the legs or uncoated parts of the filament are heated to a dull red, but the coated part, because of its greater conductivity and radiating surface, is not visibly heated. In 1 percent of methane the coated portion is active catalytically and becomes dull red. Its temperature rises with the percentage of methane. Conducted heat also increases the temperature and coloring of the filament legs. Thus there are combinations of color for every percentage of methane, and one who is skilled in the use of this detector can readily detect methane concentrations of 1 to 8 percent and estimate the lower percentages to the nearest one half of 1 percent, which is an accuracy above that of the usual flame-type detector.

This detector proved safe in laboratory tests. It is compact and portable, weighs only 2 pounds, and seems to offer commercial possibilities.

The Ralph detector was one of the first types in which heating and change in resistance of the platinum filament was shown directly by the galvanometer of a Wheatstone bridge. The successful performance of this detector was limited by lack of sensitiveness in small percentages and variations caused by poisoning of the filament by coal dust or sulphur compounds, both of which defects were eliminated in more recent detectors by operating the filament at higher temperatures.

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The U.C.C. detector is one of the later types that operate on the Wheatstone bridge principle. The bridge with its galvanometer adjusted to zero in air, becomes unbalanced when in a methane mixture because of an increase in the temperature and resistance of the platinum filament which is one leg of the bridge. The change in the filament is proportional to the amount of methane present and is shown directly in percent methane on the galvanometer.

The detector consists of four parts, all connected by flexible electric conductors. The parts are (1) the detector head containing the heated filament, (2) a meter and bridge compartment, (3) a lead type storage battery, and (4) a cap lamp attachment. All except the detector head are strapped to the user's body. The lighting attachment gives sufficient light for inspection purposes underground.

The detector gives continuous readings; it responds quickly to changes in gas percentage and thus always shows the percentage of gas in the atmosphere that immediately surrounds the detector head. The indications are reasonably accurate in low concentrations, making this detector the first practical device for determining promptly and efficiently the percentage of methane in the various ventilating air currents of mines.

The detector may be operated continuously for about 5 hours on one charge of the battery. If, however, there is opportunity for rechecking the zero scale reading in fresh air, the filament may at times be turned off and a corresponding increase in operating time secured.

The M.S.A. detector is similar to the U.C.C. detector in principle and in general performance but differs from it in the following details:

The heated filament is inclosed in the meter and bridge compartment and the mixture to be tested is circulated past it by means of an aspirator bulb and a sampling hose. Due to the fact that the filament is exposed to the test mixture at the will of the operator and that the filament soon burns all of the combustible gas from its surroundings if the mixture is not being replenished, a zero scale setting can be made on this detector at any time and place. This permits turning off the filament between successive readings and conserves the battery supply.

There are two models of the M.S.A. detector. One is combined with an Edison electric cap lamp and gets its filament current from the lamp battery. The other is supplied by a battery of two no. 6 dry cells and has no lighting attachment.

Both models weigh approximately the same - 18 pounds. The dry-cell model is complete in one box unit; the storage-battery model has its weight more distributed.

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The M.S.A. detector shows the methane concentration directly in percent. It is equipped with an expansion or storage chamber on the aspirator side of the filament chamber. There are several restrictions to the flow of gas through the intake line and filament chamber housing. Thus successive operations of the aspirator bulb, by lowering the pressure in the expansion chamber, cause almost constant flow of the gas sample past the filament. The effect is the same as though the filament were actually in the mixture at the point from which the sample is taken. This makes the detector respond quickly to changes in the concentration at the point of sampling and thus permits ready exploring of mine rooms and air courses. The use of a dryer in the sampling line insures adequate accuracy even in the lower concentrations.

Field Tests

Although detectors such as the U.C.C. and M.S.A. do not solve the problem of placing a reliable detector in the hands of every coal miner, they have proved valuable in the hands of skilled fire bosses and mine officials in that they make possible an accurate and quick determination of the condition of a mine atmosphere and thus form the basis for greater efficiency and safety in mine ventilation.

Recently, George S. McCaa, State Mine Inspector for Pennsylvania, used a M.S.A. type of methane detector in making a detailed study of the mine atmosphere in outlet returns in 13 bituminous-coal mines. Nine of these mines were classified as gaseous, and four as nongaseous mines. Data resulting from his study are shown in the following tabulation:[4]

Methane Analysis - Readings at Outlet

Mine No.	Air-sample analysis	Methane detector reading	Cubic feet of methane in 24 hours	Check samples	
				No.	Average error
1	0.13	0.15	500,000	8	0.05 Low
2	.10	.11	225,000	5	.02 "
3	.11	.08	80,000	1	.03 "
4	.09	.08	218,000	2	.02 "
5	.01	.04	1,800	1	.03 High
6	.19	.17	820,000	3	.03 Low
7	.35	.32	605,000	4	.02 "
8	.43	.45	1,050,000	6	.04 "
9	.09	.06	270,000	3	.03 "
10	.18	.20	700,000	11	.03 "
11	.03	.07	5,250	1	.04 High
12	.07	.08	22,000	2	.01 "
13	.01	.01	-	-	-
-	.02	.02	864	2	.00

4 Taken from a paper read by McCaa at the December 1932 meeting of the Coal Mine Institute of America, Pittsburgh, Pa.

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The following data from tests of mine returns by Bureau of Mines engineers using U.C.C. detectors show results comparable to those obtained by McCaa with an M.S.A. detector:

Results of U.C.C. detector tests of mine-return atmospheres

Mine No.	Return	Analysis (percent CH_4)	Detector reading (percent CH_4)	Error (percent CH_4)
1	Cross mains	0.40	0.45	+0.05
1	do.	.25	.27	+ .02
1	2 and 3 west	.10	.02	- .08
1	Split 2	.00	.04	+ .04
1	1 northwest	.10	.04	- .06
1	19 butt	.00	.09	+ .09
1	West side	.20	.21	+ .01
2	South side	.38	.42	+ .04
2	North side	.35	.31	- .04
2	Split 4	.55	.63	+ .08
2	Split 3	.50	.55	+ .05
2	Splits 5 and 6	.25	.43	+ .13
3	Split 4	.07	.08	+ .01
3	1 butt	.30	.31	+ .01
3	1 return	.20	.14	- .06
4	6, 7, 8, and 9 returns	.30	.43	+ .13
4	6 west	.50	.62	+ .12
4	Main south	.25	.23	- .02
4	Main north	.20	.13	- .07

CONCLUSION

It is interesting to review the evolution of methane-detecting devices from the safety aspect. The open-flame method first used was extremely hazardous and is unthinkable today as a safe manner of detecting gas. The unbonneted Davy lamp when properly assembled was safe in low-velocity atmospheres, but would be unsafe in velocities used in present-day practice. Later modifications of the Davy lamp were safer and the lamps used at present in American mines are designed to withstand velocities up to 2,500 feet per minute - a value approximately four times that which was safe for the Davy lamp. The Burrell, the U.C.C., and the M.S.A. detectors are all considered safe in high-velocity atmospheres, and in view of their mechanical construction are probably safer than devices having an open flame protected by a glass cylinder bonnet and gauzes, as is the case of the usual flame-lamp type of detector.

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In comparing the various detectors they should be grouped as to types of service or application.

Group 1.- Flame-type detectors and detectors such as the Martienssen, that do not permit of accurate determinations but are simply devices for detecting the presence of methane and of estimating its percentage, may be called "detectors."

Group 2.- Those detectors that have calibrated scales through which more accurate determinations can be obtained may be called "indicating detectors."

Group 3.- Detectors such as the singing-flame lamps and the Ringrose detector should be called "alarms."

Detectors (group 1) are the most widely used. They were the first developed and are still considered the basis of comparisons and of State mine regulations relative to methane detection. As a rule these detectors are inexpensive, rugged, and reliable.

Flame-type detectors give warning of oxygen deficiency, and in every mine their use fulfills the law with respect to methane detection.

There are two different services for methane detectors: (1) The checking of all working places just before workers enter the mine and the testing of working places by machinemen and shot firers previous to and during their operations. (2) Determinations of methane content at all faces and sections of the mine in order to lay out and maintain adequate ventilation.

Perhaps the chief difference in these two services is in the relative number and therefore the total cost of the detectors required per mine. Gassy mines require many detectors for use by the fire bosses, machinemen, and shot firers, whereas one instrument of the indicating detector group may be sufficient.

Another distinguishing difference is the kind of service required. A fire boss has a definite section of a mine to cover in approximately 3 hours. Because of the limited time and long walking distance, devices of the detector group that are lightweight and sturdy and permit relatively quick determinations are suitable for the fire boss. They are also suitable for use by the less skilled machinemen and shot firers.

None of the present devices of the indicating detector group is entirely satisfactory for use by fire bosses, machinemen, and shot firers; that is, they lack one or more of the following desirable features: (1) Low cost, initial and upkeep; (2) quick determination; (3) sturdiness; (4) simplicity. On the other hand, at least two detectors - the U.C.C. and M.S.A. - are very satisfactory for checking the gaseous condition of a mine and improving the ventilation.

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Indicating detectors of this type permit ready exploring of all parts of a mine; with them reliable data can be obtained at once, which is much more satisfactory than waiting for laboratory analyses of the fewer samples taken with vacuum sample bottles. Desirable changes in ventilation can be more readily anticipated and made; this tends toward greater efficiency in ventilation and greater safety for every one in the mine.

Devices of the third or alarm group are not used in American mines. The writers believe that under American conditions none of these alarms would prove sufficiently reliable, especially at lower percentages of methane, as they are subject to changes in adjustment, fuel, conditions of contact, etc. Their use in European mines may possibly be explained by the fact that in most of the countries, control of mines and mining equipment is much more rigid and centralized than in the United States. Any alarm device that will not give alarm dependably in less than 2 percent methane would probably have little or no application in American mines.

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